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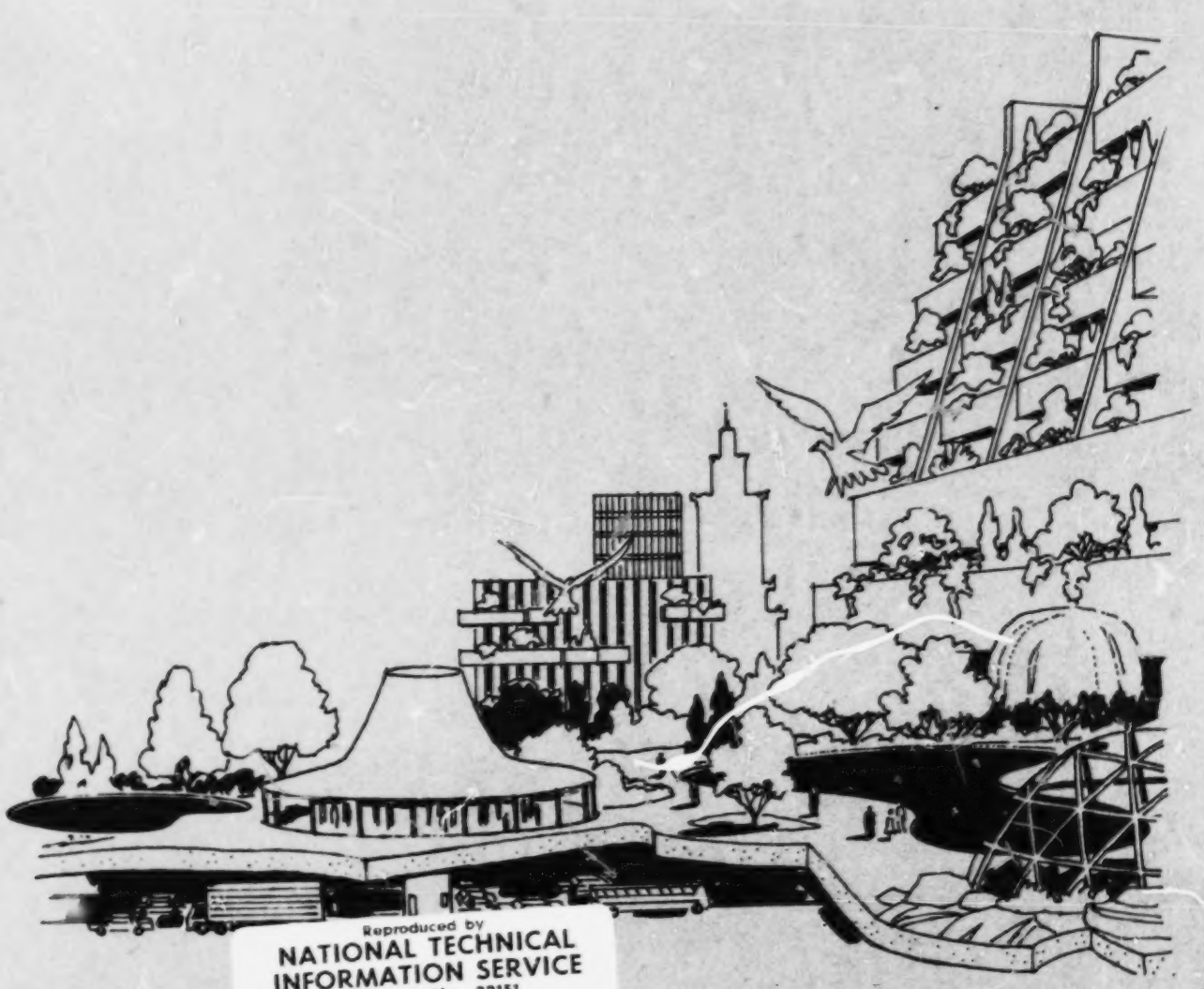
# INDUCED HYPOLIMNION AERATION FOR WATER QUALITY IMPROVEMENT OF POWER RELEASES



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5 Organization

Environmental Protection Agency
Robert S. Kerr Water Research Center
Ada, Oklahoma

6 Title

INDUCED HYPOLIMNION AERATION FOR WATER QUALITY IMPROVEMENT OF POWER RELEASES,

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16 Project Designation

~~EPA-WQO Prog. 16080 10/70~~

21 Note

I 67.13/4:16080-10/70
Copy available from GPO Sup Doc as , $0.50; microfiche from NTIS as PB/98 216, $0.95.

22 Citation

Report No 16080 ~~DWQ~~, October 1970, 32p, 15 fig, 2 tab, 21 ref

23 Descriptors (Starred First)

*Aeration, *Thermal stratification, *Impoundments, *Hypolimnion, Dissolved oxygen, Mixing, Oxygenation, Air entrainment, Thermocline, Epilimnion

25 Identifiers (Starred First)

*Water quality control, *Induced aeration, *Reservoir destratification, ~~*Hypolimnion aeration~~, Air distribution system, Oxygenation efficiency, Power release aeration

27 Abstract

Conventional hydraulic structures in most dams withdraw low flow and power releases from the poor quality hypolimnion waters during summer stratification resulting in serious degradation of long reaches of streams below dams. Induced aeration of hypolimnion waters during summer stratification has great potential in water quality management of power releases, low flow releases, and limited volumes of impoundments without costly modification of existing outlet works. Hypolimnion aeration research on power discharge quality improvement was conducted at Eufaula Reservoir in southeastern Oklahoma during the summer of 1968. Dissolved oxygen transfer efficiency of the aeration system ranged from 1.8 to 3.0 pounds of dissolved oxygen per horsepower-hour of expended energy resulting in an operating cost of 4.10 to 6.25 dollars per 1,000 pounds of oxygen incorporated into the power releases. Additional research for development and optimization of the induced aeration system is discussed.

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WR:102 (REV. JULY 1969)
WRSIC

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* GPO: 1969-359-339

# INDUCED HYPOLIMNION AERATION FOR WATER QUALITY IMPROVEMENT OF POWER RELEASES

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for the

WATER QUALITY OFFICE

ENVIRONMENTAL PROTECTION AGENCY

Program #16080---
October 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402 - Price 50 cents

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## ABSTRACT

Summer stratification in reservoirs creates large volumes of poor quality water below the thermocline. Conventional hydraulic structures in most dams withdraw low-flow releases and power releases from the hypolimnion resulting in serious degradation in long reaches of streams below these dams. A technique for improving the quality of power releases without costly modification of existing outlet works is presented. Induced aeration of the hypolimnion was tested in Eufaula Reservoir during the summer of 1968. Dissolved oxygen transfer efficiency of the aeration system ranged from 1.8 to 3.0 pounds of dissolved oxygen per horsepower-hour of expended energy resulting in an operating cost of 4.10 to 6.25 dollars per thousand pounds of oxygen incorporated in the power releases. Research needs for development of the induced aeration system are discussed.

TABLE OF CONTENTS


| Section | | Page |
|---|---|---|
| I. | Introduction. . . . . | 1 |
| II. | Procedures and Equipment. . . . . | 5 |
| III. | Evaluation. . . . . | 11 |
| IV. | Discussion. . . . . | 15 |
| V. | Acknowledgments . . . . . | 29 |
| VI. | References. . . . . | 31 |

LIST OF FIGURES


| Figure | | Page |
|---|---|---|
| 1. | Eufaula Reservoir--Vicinity Map | 3 |
| 2. | Project Location Map. | 6 |
| 3. | Temperature Distribution, August 2, 1968. | 8 |
| 4. | Dissolved Oxygen Stratification, August 2, 1968 | 9 |
| 5. | Comparison of Stratification and Induced Aeration Effects at Station 1. | 12 |
| 6. | Eufaula Dam Power Discharge Schedule. | 14 |
| 7. | Comparison of Natural Aeration and Maximum Induced Effect on the Central Pool | 16 |
| 8. | Effect of Aeration on Power Release | 17 |
| 9. | Effect of Aeration Without Power Release | 18 |
| 10. | Effect of Aeration During 4,000 cfs Power Release. | 19 |
| 11. | Effect of Aeration During 8,000 cfs Power Release. | 20 |
| 12. | Effect of Aeration During 12,000 cfs Power Release | 21 |
| 13. | Increase of Dissolved Oxygen in 4,000 cfs Power Release Periods During Reservoir Induced Aeration. | 23 |
| 14. | Increase of Dissolved Oxygen in 8,000 cfs Power Release Periods During Reservoir Induced Aeration. | 24 |
| 15. | Increase of Dissolved Oxygen in 12,000 cfs Power Release Periods During Reservoir Induced Aeration. | 25 |

## LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1. | Background Monitoring Data. . . . . | 5 |
| 2. | Oxygenation Capacity for Various Aeration Systems . . . . | 28 |

## SUMMARY

During the summers of 1967 and 1968, induced aeration research was conducted in Eufaula Reservoir in eastern Oklahoma. The first summer's work was the pilot study of aeration research by the Robert S. Kerr Water Research Center and was the first destratification research conducted in a very large reservoir. The pilot-study research was the first attempt to determine the limiting effects of a particular sized aeration-distribution system centrally located in a large body of water where effects are unconfined. The details of the 1967 research are reported in Pilot Study of Dynamics of Reservoir Destratification.[17] The second year's research, which this report details, was a follow-up study of the 1967 pilot study.

The design of the aeration system used in the 1968 study was based on the results of the 1967 study. The compressor was located on Eufaula Dam because of its size and weight and the availability of an adequate power supply. Compressed air was piped to the distribution system located on the reservoir bottom about 750 feet upstream. Advantage was taken of the location of the distribution system to measure not only the outward expansion of aeration effects in the hypolimnion and upstream limits of aeration effects but also the effects of hypolimnion aeration on downstream power releases.

Since the study of hypolimnion effects on power releases was conducted during a period of unaltered normal power release schedules, previously established by the U. S. Army Corps of Engineers and the Southwest Power Administration, the most ideal aeration test conditions were not possible. However, care was taken to coordinate the time of the aeration test and monitoring periods with periods of stable power discharge in order to collect the most reliable data possible.

It was found that induced aeration of the hypolimnion immediately upstream of power penstock intakes is a very effective, low-cost method of increasing dissolved oxygen in downstream releases. Without supplemental aeration, dissolved oxygen is slightly increased in downstream releases during normal power operation by the entrainment of waters of higher dissolved oxygen concentrations in the upstream flow net from the epilimnion. However, dissolved oxygen was greatly increased in the upstream flow net for each incremental increase in power discharge by upstream hypolimnion aeration. Statistical analysis of data collected during aeration test showed that dissolved oxygen was increased in downstream releases between 55 and 80 percent (depending on the discharge rate) above the concentration during static stratified conditions.

In comparison with other methods tested in recent years, this technique had equal or greater oxygenation efficiencies (expressed in pounds of oxygen added per horsepower-hour of energy used) than most other systems. Since an electrically driven compressor can be used in this type of aeration

system and electrical power is usually available at each dam, there is an opportunity to utilize this technique in most power-producing reservoirs at minimal cost. Installation of an aeration system similar to the one studied would require no modification of outlet works or loss in efficiency of the existing power equipment.

## RECOMMENDATIONS

It is recommended that induced aeration of hypolimnion waters be further studied in reservoirs of various depths during extreme stratification. Further research should be planned in detail and conducted at reservoirs where the power discharge schedule can be modified in such a way that each discharge rate of an array of power discharge rates could be held constant for several days during continuous induced aeration. Rigid control of power discharge conditions will allow the stability necessary for very accurate measurements of aeration effects for each rate of power discharge. Tests should be conducted in a number of reservoirs, each with different physical conditions. Study situations should be varied with respect to depth of stratification, depth of reservoir, and chemical concentrations in the hypolimnion. The aeration system should be placed at different points upstream of the dam and tested with a range of air volumes at each placement. In this manner, the most efficient placement distances from the power penstocks with respect to the air input can be determined. The distribution system should be tested at various depths below the thermocline at the position of optimum upstream placement. Other chemical parameters in addition to dissolved oxygen should be measured in the power releases immediately below the dam. Specifically, the nitrogen series, hydrogen sulfide, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and phosphates should be measured throughout the aeration test periods.

When the system has been fully evaluated by this technique, it can then be installed and demonstrated in any reservoir where water quality problems exist in downstream releases.

# SECTION I

## INTRODUCTION

Man in his quest to harness water by constructing dams behind which water is impounded for power production, irrigation, flood control, navigation, and other purposes has produced unanticipated results, some of which are detrimental to his environment. As the movement of water is retarded and streams are allowed to deepen, the natural reoxygenation capability is reduced. The reduction of this capability becomes even greater where waters have been allowed to become stilled as in lakes and impoundments.

During summer months, deep lakes and impoundments develop the classic "sandwich" of epilimnion-thermocline-hypolimnion, commonly known as thermal stratification.[1] During early summer, the surface waters begin to warm, as atmospheric temperatures increase, and a strata of less dense water is formed above the cold bottom waters. As the surface strata (epilimnion) warms and is wind circulated, the thermocline or middle strata is developed and acts much as a diaphragm preventing surface-induced circulation below that depth. Since waters below the thermocline (hypolimnion) cannot be reoxygenated, they soon become void of oxygen by chemical reduction processes and biological respiration, forming a stagnant mass. As dissolved oxygen becomes depleted in hypolimnion waters, many deteriorating chemical reactions also occur leaving the water mass high in hydrogen sulfide, phosphates, nitrates, and various toxic metals.[1,2,3] Often, these changes go unnoticed through the months of summer stratification, unless the water is being used for public water supplies or is being released downstream through low-level power generating outlet works or low-flow release gates.

Hypolimnion releases often cause downstream fish kills and are hazardous to people in the area breathing the toxic hydrogen sulfide gases released. Since the water is void or very low in dissolved oxygen it is not useful for stream flow augmentation and high concentrations of undesirable chemical compounds may be released into the streams.

In recent years, the increased public awareness of environmental problems, the national demand for improved water quality, and requirements for greater volumes of potable water have encouraged researchers to attack the water quality problems arising from impoundment stratification.

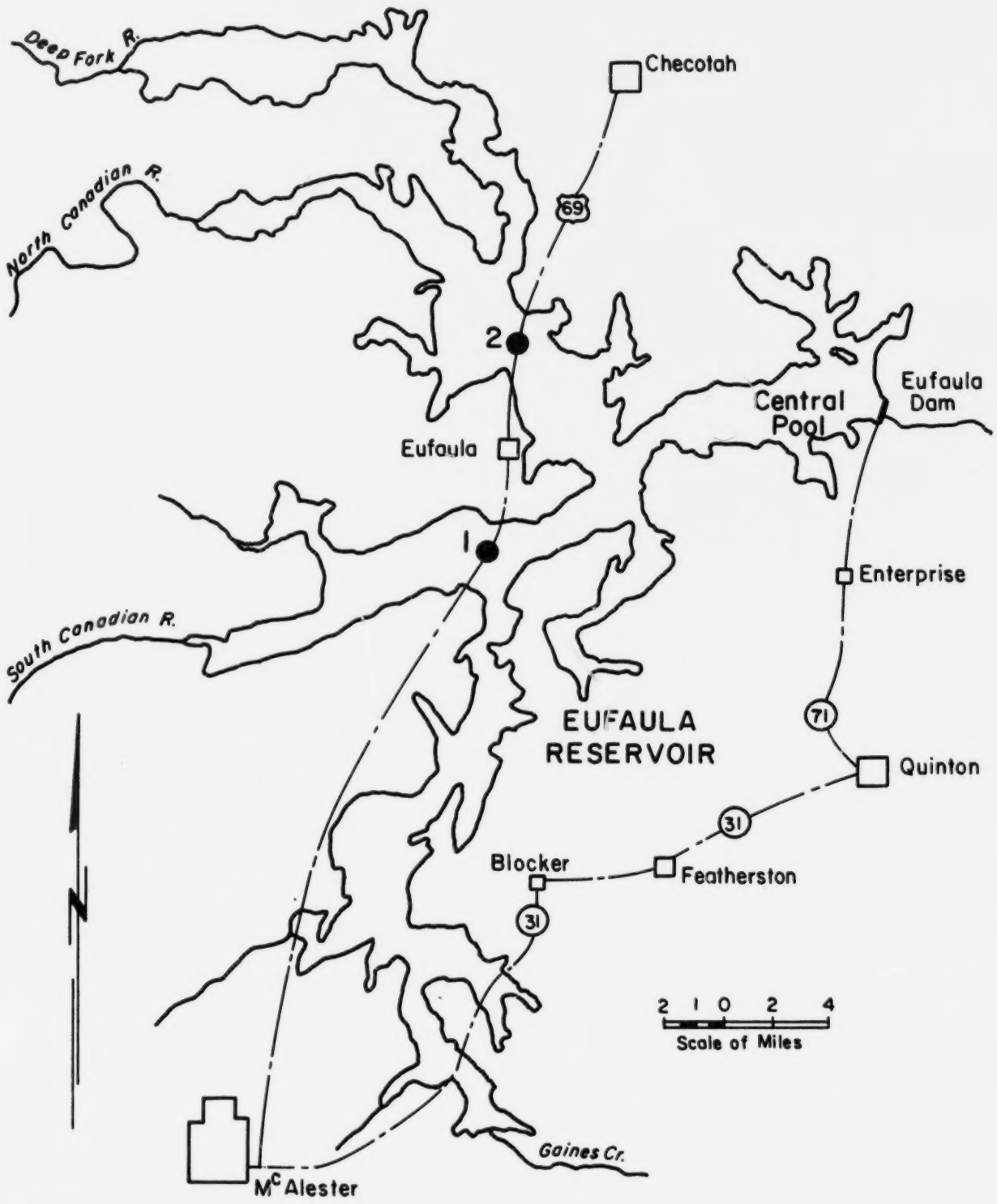
Research in eliminating stratification has been primarily directed toward testing various devices for circulation of the entire water mass in small lakes. These devices range from mechanical pumps[4,5] to various types of diffused air releases and pure oxygen systems.[6,7,8,9,10,11] These systems have primarily been evaluated by determining the rate of induced oxygenation of the entire water mass in which they were installed, efficiency of oxygen transfer in the entire water mass per unit of power input, and observation of changes in various chemical parameters. Other research

has been directed toward improving power and low-flow releases. Research in this area includes studies of multilevel outlet works for selective withdrawal,[12,13] vented and forced air injection into power turbines,[14] submerged weirs upstream of power turbines,[15,16] and various spray devices attached to low-flow release structures such as the Howell-Bunger valve tested by the Tennessee Valley Authority. Aeration effects of various configurations and designs of stilling basin energy dissipaters have also been studied. While it is true that a measure of correction of the downstream problems is possible with multilevel outlet works, submerged weirs, vented power turbines and various other devices, the initial cost of installation is usually great. As a result, they have not been fully evaluated to determine if they are economically justifiable when compared with other methods of aeration. These structures are few and are not being constructed extensively in problem reservoirs because of their cost, loss of generating efficiency, and the uncertainty in achieving the desired water quality effects.

In past years, most reservoirs constructed throughout the United States were economically justified on the basis of benefits derived from flood control, hydroelectric power, water supply, navigation, and more recently recreation without regard for water quality either in the impoundment or its release. As a result, the present operation of many reservoirs is dictated by the design of outlet works such that power releases and flows withdrawn during summer stratification cause serious downstream quality problems. Outlet works are located in some dams at levels where it is virtually impossible to release anything but poor quality water during the summer season. This has resulted in design and construction agencies giving high priority to water quality considerations in their planning and design phases of all new dams. However, the problem of poor quality releases from existing structures must be corrected if streams and reservoirs in river systems are to be significantly improved.

Little research has been conducted to determine the feasibility of improving water quality by induced aeration immediately upstream of existing power intake structures. The research described in this report was an evaluation of the diffused aeration technique in storage reservoirs to aerate hypolimnion waters withdrawn during power generation. The project was conducted in 1968 at Eufaula Reservoir, a Corps of Engineers Reservoir located in eastern Oklahoma.

Eufaula Reservoir, the largest reservoir in which aeration research has been conducted, has a surface area of 102,500 acres and a storage of 2,800,000 acre-feet at power pool elevation 585 ft (Figure 1). The central pool, where the major portion of the research was conducted, has a surface area of 10,800 acres and a volume of about 570,000 acre-feet at 585 feet elevation.




CONTROL STATIONS —●

FIGURE 1 - EUFAULA RESERVOIR VICINITY MAP

## SECTION II

## PROCEDURES AND EQUIPMENT

In January 1968, 17 sampling stations were located in the central pool of Eufaula Reservoir by triangulation surveys (Figure 2). Vertical profiles of temperature and dissolved oxygen were taken at 5-foot intervals every two weeks during winter and spring to establish antecedent conditions and to determine the progress of stratification. Two upstream stations (Stations 1 and 2 on Figure 1) which were outside the influence of the aeration system were also monitored and used as control stations.

In addition to monitoring of the 17 reservoir stations, dissolved oxygen and temperature of downstream power releases were also measured to determine the influence of normal reservoir stratification on power releases. Table 1 illustrates how the dissolved oxygen continued to be reduced in the power releases while the temperature continued to increase during development of stratification conditions.

TABLE 1

BACKGROUND MONITORING DATA

| Date | Discharge cfs | Dissolved Oxygen mg/l | Temp-°C | D.O. % Saturation |
|---|---|---|---|---|
| July 5,1968 | 12,000 | 5.0 | 21.7 | 58.1 |
| July 10,1968 | 12,000 | 3.8 | 23.0 | 44.9 |
| July 18, 1968 | 8,000 | 3.4 | 23.5 | 40.8 |
| July 25, 1968 | 8,000 | 3.0 | 24.0 | 35.7 |
| August 2, 1968 | 8,000 | 3.0 | 24.0 | 35.7 |

Stratification was hampered during the spring months by unusually heavy rainfall and unseasonably cool weather. During May and June, high inflows resulted in the reservoir rising to a record elevation of 590.5 feet. At this elevation, it was necessary to release stored water through the tainter gates, as well as through the power penstocks, for about 10 days. During these high releases, work on installation of the air distribution system on the reservoir bottom, a short distance upstream of the dam, had to be suspended for safety reasons, resulting in considerable delay. These tremendous discharges, together with the large inflow, caused the upstream turbid waters to move downstream from the upper reaches of the reservoir, engulfing the central pool. This movement of water through the reservoir mixed the central pool and slowed stratification.

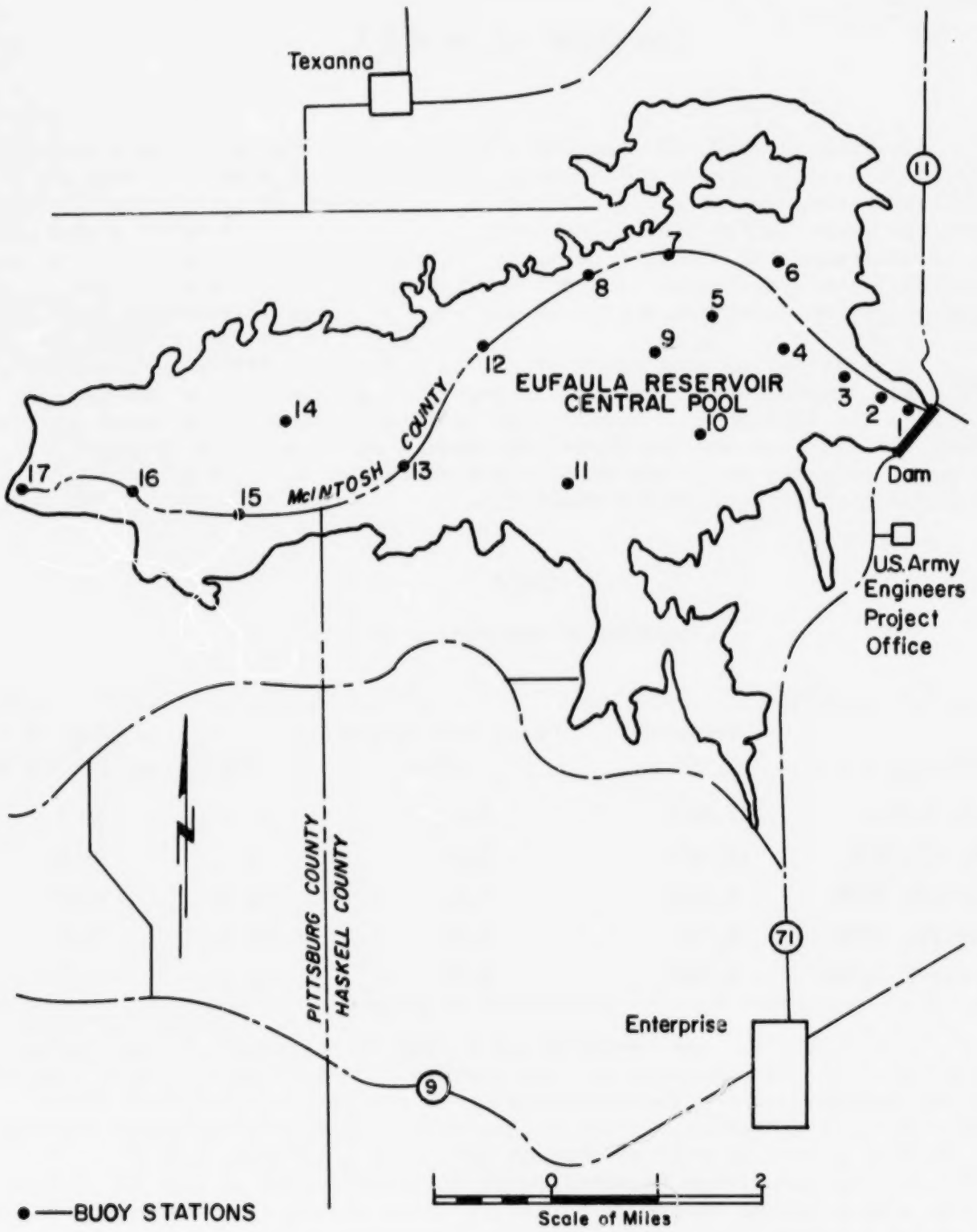



FIGURE 2 – PROJECT LOCATION MAP

Stratification finally began in mid-July, and a weak thermal stratification pattern became stable by the end of July. Figure 3 shows temperature profiles for stations in the central pool on August 2, just prior to initiation of aeration. Because of the unusually large flow through the reservoir, the "classical" temperature profiles did not develop. There was, however, an identifiable thermocline between the 30- and 40-foot depths. This compared with a thermocline depth in 1967 of about 25 feet which was well established at the end of June when the first measurements were made.

The dissolved oxygen profiles for the central pool on August 2 are shown on Figure 4. Stratification is more evident from the dissolved oxygen profiles than from the temperature profiles. Oxygen concentrations varied from 7.3 to 8.3 mg/l on the surface and were fairly constant to a depth of about 30 feet. Below 30 feet, oxygen concentration was reduced rapidly to zero at 60- to 70-foot depths.

The design of the air distribution system used in this research was based on the performance of the system used in the 1967 pilot study and the volume of effect desired. The system consisted of six 40-foot arms of 4-inch diameter pipe, each arm having eight equally spaced microporus diffusers. One end of each of the six arms was attached to a central header of 10-inch pipe to which the air supply hoses were coupled. The arms were equally spaced around the central header, $60^{\circ}$ apart in a horizontal plane. The diffusers were commercially fabricated, microporus porcelain, hollow candles, having a length of 8-3/16 inches and an interior diameter of 1-1/2 inches. The bubble-forming microporus capillaries had an average radius of $25 \times 10^{-4}$ cm resulting in 27 percent porosity for each candle.

Air was supplied to the distribution system through two 900-foot lengths of 2-1/2 inch flexible hose. The air distribution system was located approximately 750 feet upstream of the power penstock intakes where the water depth was 95 feet. The distribution system was supported 2.5 feet above the bottom.

The air compressor was a 1,200 cubic feet per minute (cfm) electrically powered, rota-screw-type machine capable of supplying this volume at 125 pounds per square inch gauge (psig) pressure. The compressor was placed on the top of Eufaula Dam near the roadway above the power penstocks due to its size and weight and for convenience to a high-voltage power source. Air delivered from the compressor was filtered through a "scrubber" to remove oil and water vapor before it passed through the air-metering equipment. Instrumentation was installed to continuously record air volume, temperature, pressure, and power utilization. Air temperature, air pressure, and power utilization were measured directly. Volume of air flow was calculated from a record of pressure differential and inlet pressure for air at $60^{\circ}$F and corrected to actual air temperatures.

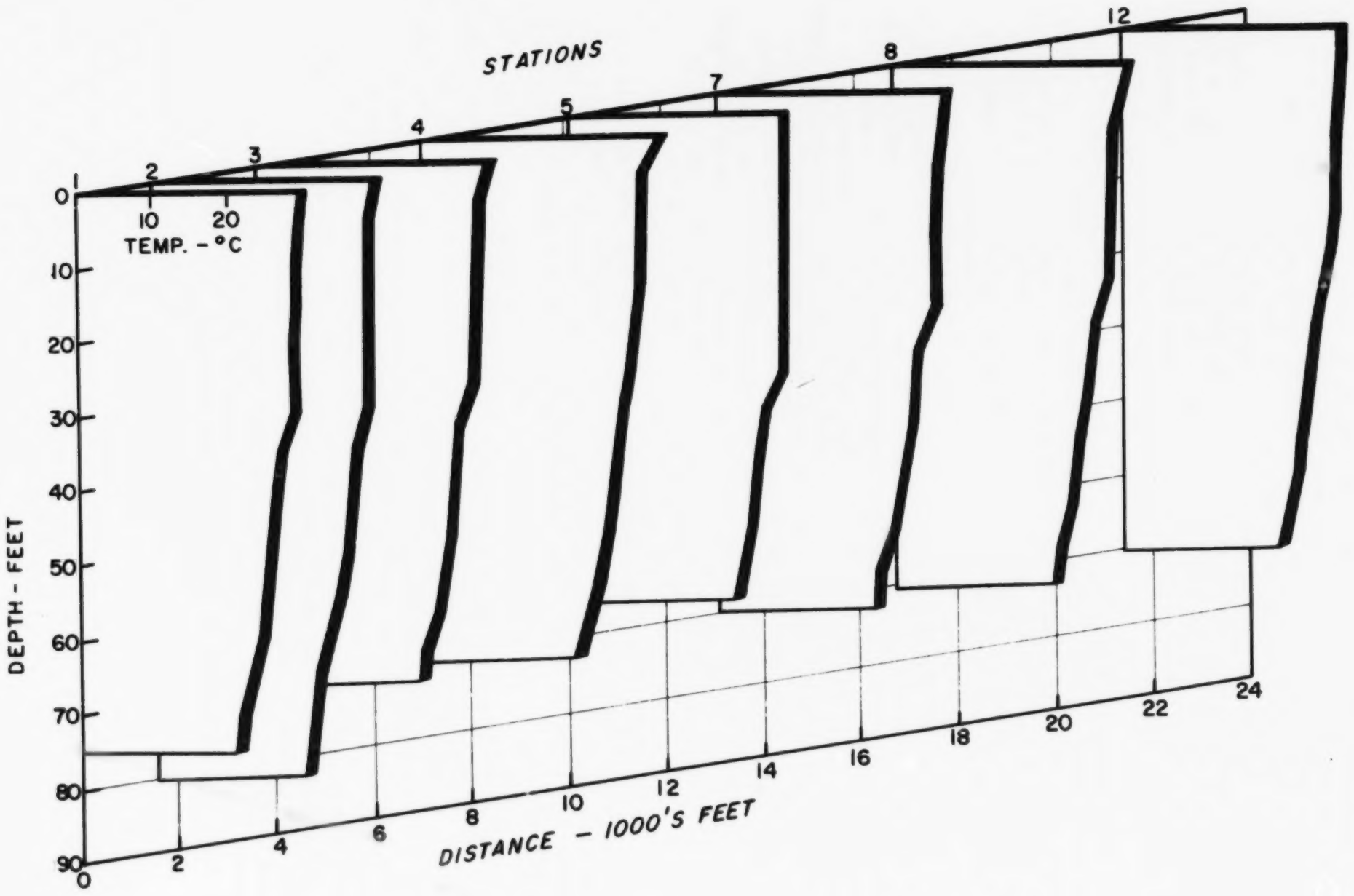



FIGURE 3 - TEMPERATURE DISTRIBUTION - AUGUST 2, 1968

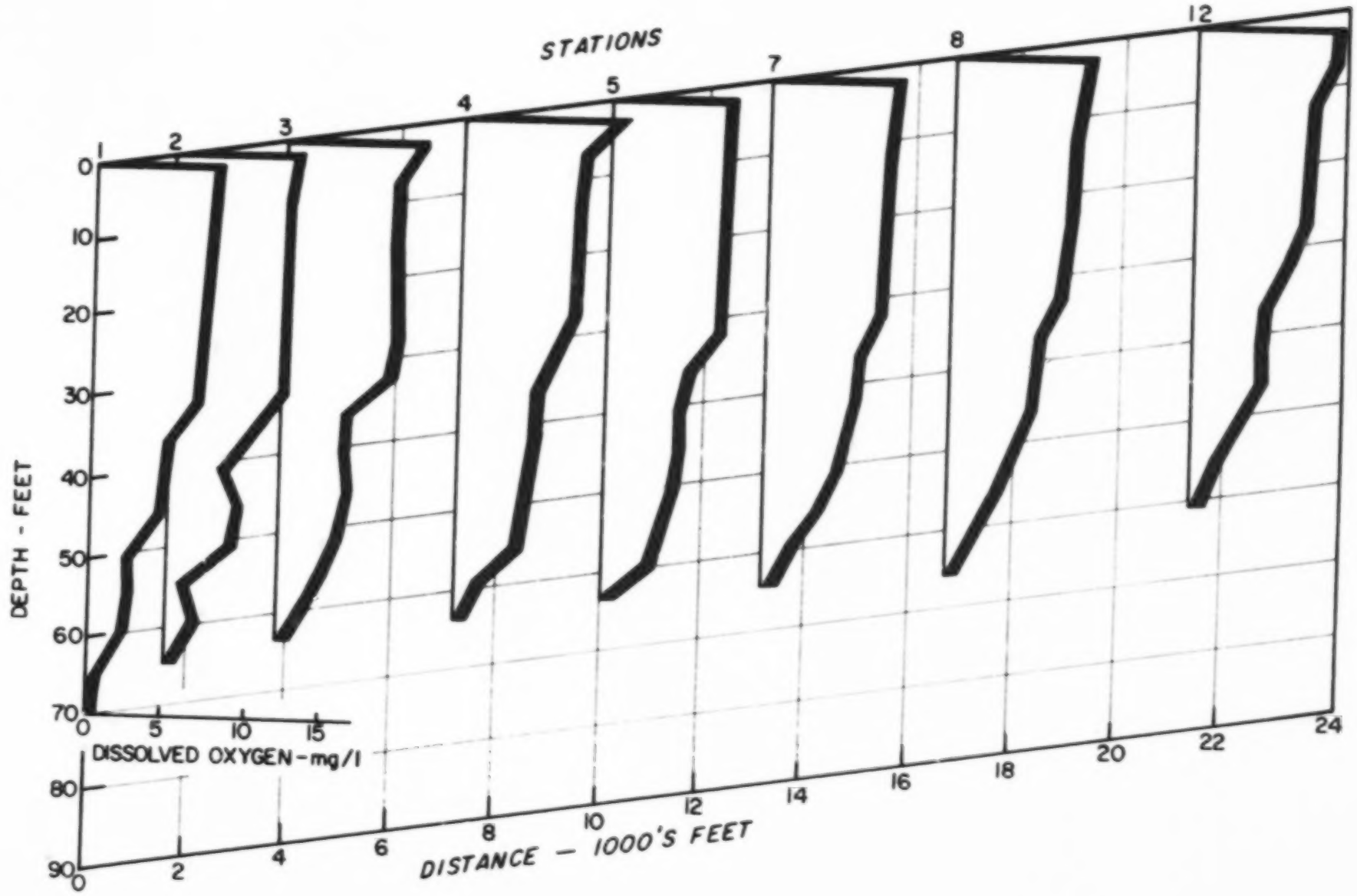



FIGURE 4 - DISSOLVED OXYGEN STRATIFICATION - AUGUST 2, 1968

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## SECTION III

## EVALUATION

Aeration started on August 2, with a constant flow of compressed air being delivered at the rate of 1,200 cfm to the air distribution system. The air pressure was 55 psig and the temperature was 150°F at the air recording meter on top of Eufaula Dam. The air pressure was reduced to about 45 psig at the submerged distribution system as a result of friction losses and the hydrostatic head of the water above the system. Air was measured in the distribution system by a remote thermistor which had a connector at the lake surface. The air temperature was reduced from 150°F on the dam to 75°F as it was released in the reservoir bottom. The compressed air was cooled in the hose in transit to the distribution system as a result of heat lost to the cooler surrounding water mass.

Reservoir stations were monitored twice weekly after aeration began. Immediately before the start of aeration on August 2, vertical profiles of dissovled oxygen and temperature characterized the stratification conditions of the reservoir at Station 1, located approximately 200 feet east of the distribution system (Figure 5). These antecedent profiles were similar to the average of the 17 stations, but the temperature at Station 1 was slightly warmer throughout the depth as a result of the sheltering effect near the dam. Antecedent conditions are compared with conditions on August 27 after 26 days of aeration. During this period, aeration was continuous except for interruptions to service equipment and to correct operating problems.

A period of intense monitoring of the water being drawn into the power penstocks was conducted beginning on August 29 and lasting until September 15. Dissolved oxygen concentrations of the power discharges were measured for each discharge rate to characterize the dissolved oxygen concentration with respect to flow rate. Eight monitoring stations (designated A through H) were located at intervals of 100 feet between Eufaula Dam and the air distribution system for collection of vertical profiles of temperature and dissolved oxygen. These profiles allow an accurate characterization of the behavior of the flow net temperature and dissolved oxygen layers entrained into the penstocks during power release periods. The work schedule was coordinated with the power plant operators in order that flow net profiles and downstream discharges could be monitored during the most stable portion of each release period. For example, during flow net monitoring, the hourly power release schedule for the following day was reviewed in order to schedule monitoring of the flow net for flow rates of 4,000 cfs, 8,000 cfs, and 12,000 cfs which corresponded to operating one, two, and three turbines. Downstream temperature and dissolved oxygen data were collected simultaneously with each flow net profile monitoring period.

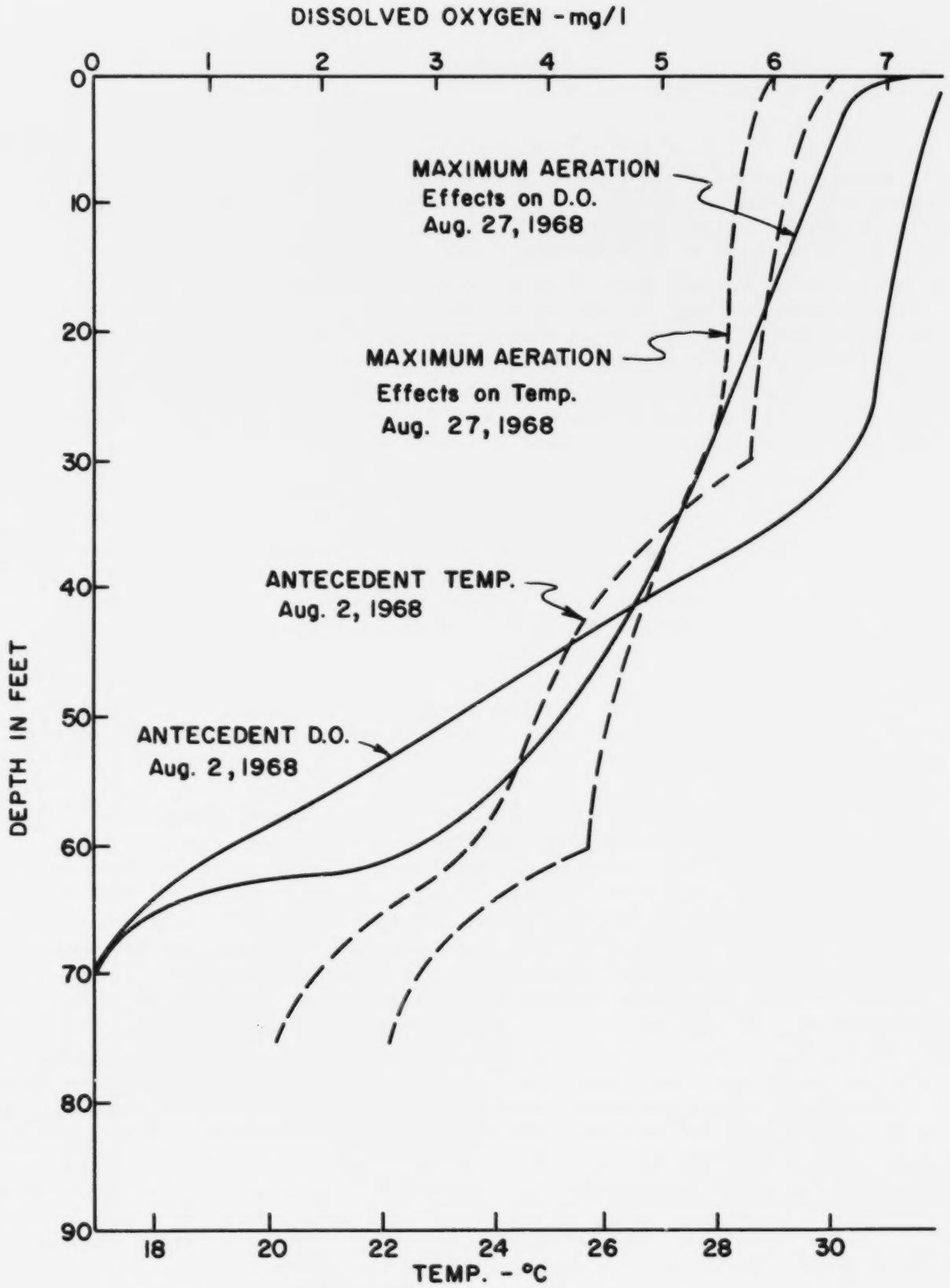


FIGURE 5 - COMPARISON OF STRATIFICATION AND INDUCED AERATION EFFECTS AT STATION I

The power release schedule could not be modified during the aeration study to allow long-term testing of power release rates. The power discharge schedule and periods of aeration are shown in Figure 6. The duration of constant flow periods was not sufficient for determination of downstream dissolved oxygen change rates with respect to time from the start of aeration. A modified operating schedule to allow these test measurements would have been ideal for statistical comparison of actual operational dissolved oxygen and temperature changes with respect to duration of aeration and power discharge rates.

During monitoring periods for each of the three power discharge rates tested, downstream temperature and dissolved oxygen were measured after the flow had stabilized. Measurements were conducted both prior to and during the period of aeration for each change in power discharge. In analyzing the data and correlating it with the actual power release schedule, it was found that some of the downstream measurements would have to be discarded since they were taken during times when power releases were being changed in the power house. Therefore, only dissolved oxygen values of power releases that were collected in the most stable power release periods were selected for detailed analysis.

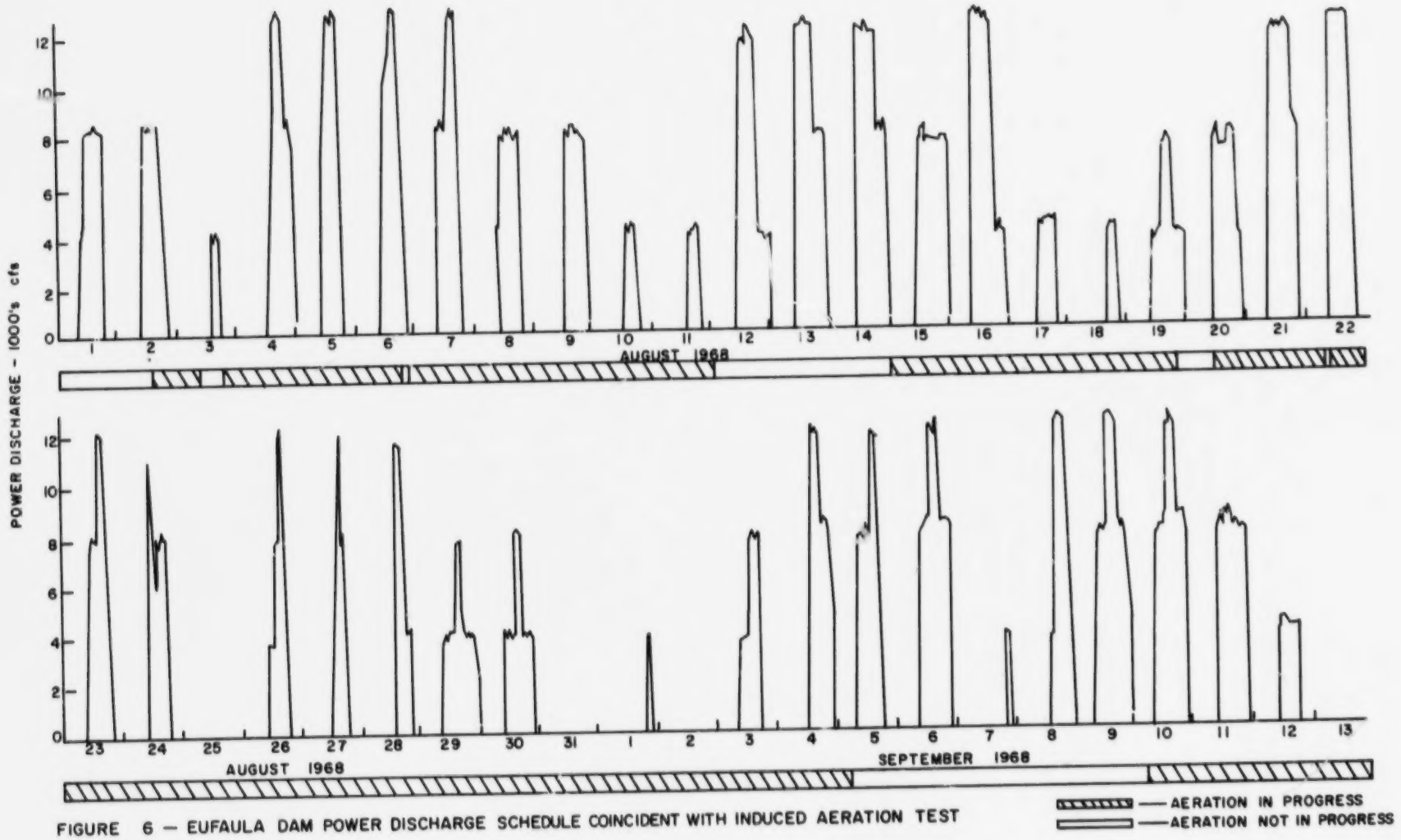


FIGURE 6 — EUFAULA DAM POWER DISCHARGE SCHEDULE COINCIDENT WITH INDUCED AERATION TEST

## SECTION IV

## DISCUSSION

Aeration was begun on August 2, and maximum aeration effects in the reservoir were achieved on August 27. The greatest effects were realized at Station 1, located near the distribution system, although the influence of aeration was detectable as far as 11,000 feet upstream. Dissolved oxygen profiles for the two dates show that oxygen was added between the 40- and 70-foot depths at Station 1 (Figure 5). However, there was a reduction in oxygen from the surface to a depth of 40 feet. These lower dissolved oxygen concentrations resulted from the upward movement of hypolimnion water. By comparing temperature profiles, representing the period of aeration (Figure 5), it is evident that a reverse effect occurred in the temperature relationships. The temperature profiles indicated that bottom waters were warmed and surface waters cooled by the pumping action of the air distribution system.

The aeration effect upstream of Station 1 formed a horizontal cone or wedge of oxygenated water with detectable limits reaching upstream between Stations 4 and 5, (Figures 2 and 7). The maximum horizontal wedge of aerated hypolimnion water, illustrated by the intersection of the dashed and solid lines in Figure 7, was approximately 29,400 acre-feet. This is less than half that reported in the pilot study of 1967.[17] This horizontal wedge of aerated water did not expand at the rate anticipated. Apparently, the volume of aerated hypolimnion water in the reservoir was not diffusing upstream at the rate anticipated because the aerated water was being discharged through the dam during power generation. Power discharge volumes exceeded the maximum volume aerated in the hypolimnion; therefore, only during periods when power generation was not in progress was any appreciable volume of oxygenated water accumulated in the hypolimnion.

It was observed during the course of aeration that dissolved oxygen concentrations of water released during power generation increased from 3 mg/l immediately before aeration began to a range of 4.0 to 5.3 mg/l, depending on the volume of power releases and the time of observation after the start of aeration (Figure 8). The intensive study conducted between August 29 and September 15 was for the purpose of defining the aeration effects on the flow net entering the power penstocks and to relate these effects to water quality changes in the power releases.

Results of flow net changes are illustrated in Figures 9, 10, 11, and 12. Figure 9 illustrates both the effect of normal stratification and the aeration operation on the dissolved oxygen layers between Eufaula Dam and the air distribution system after a normal weekend of no power releases. Conditions presented are averages of all periods having no power releases. It should be noted that aeration during the periods of no power release resulted in the 4.0 mg/l strata of dissolved oxygen being developed approximately eight feet deeper than under stratification conditions with no aeration.

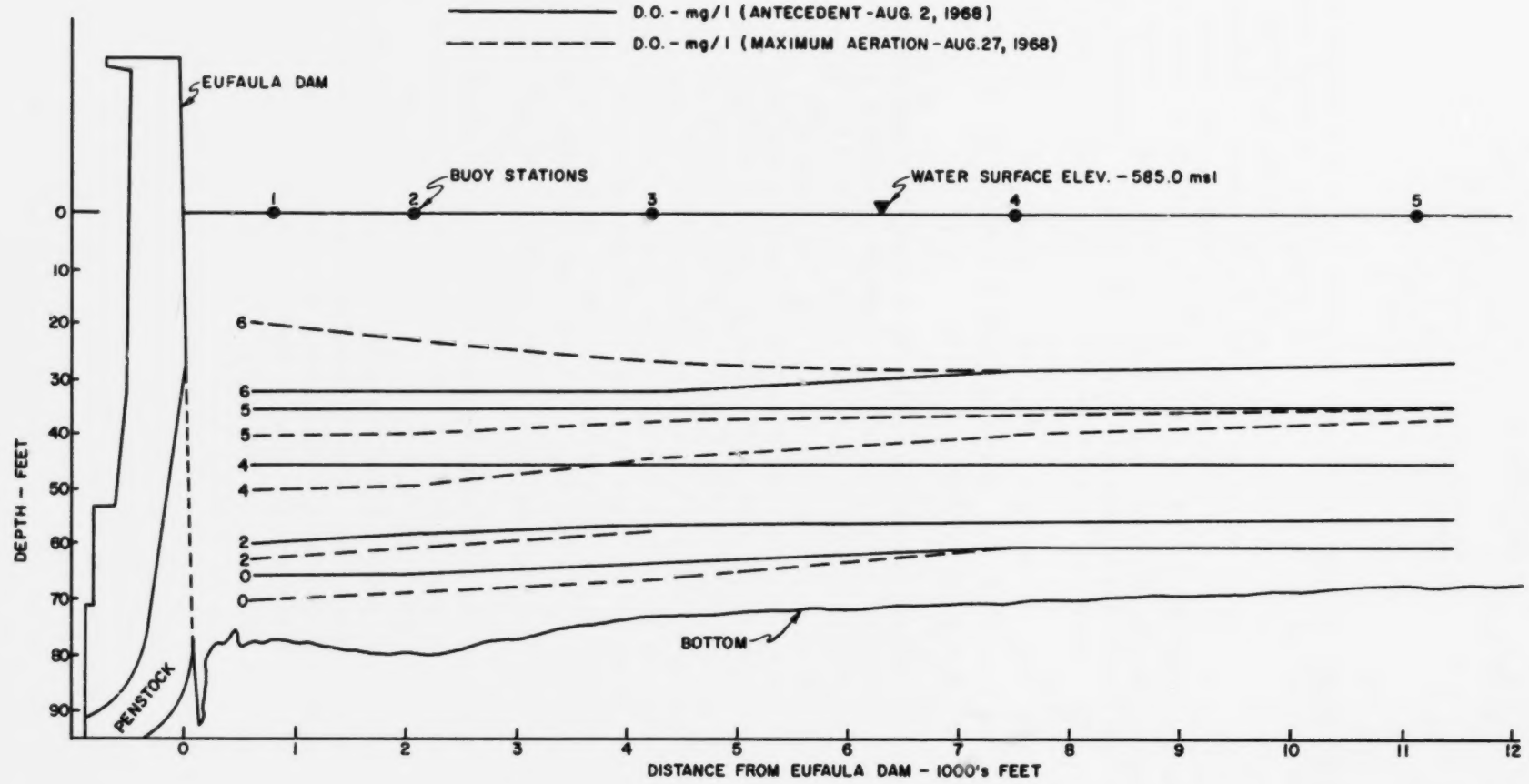


FIGURE 7 — COMPARISON OF NATURAL AERATION AND MAXIMUM INDUCED EFFECT ON THE CENTRAL POOL

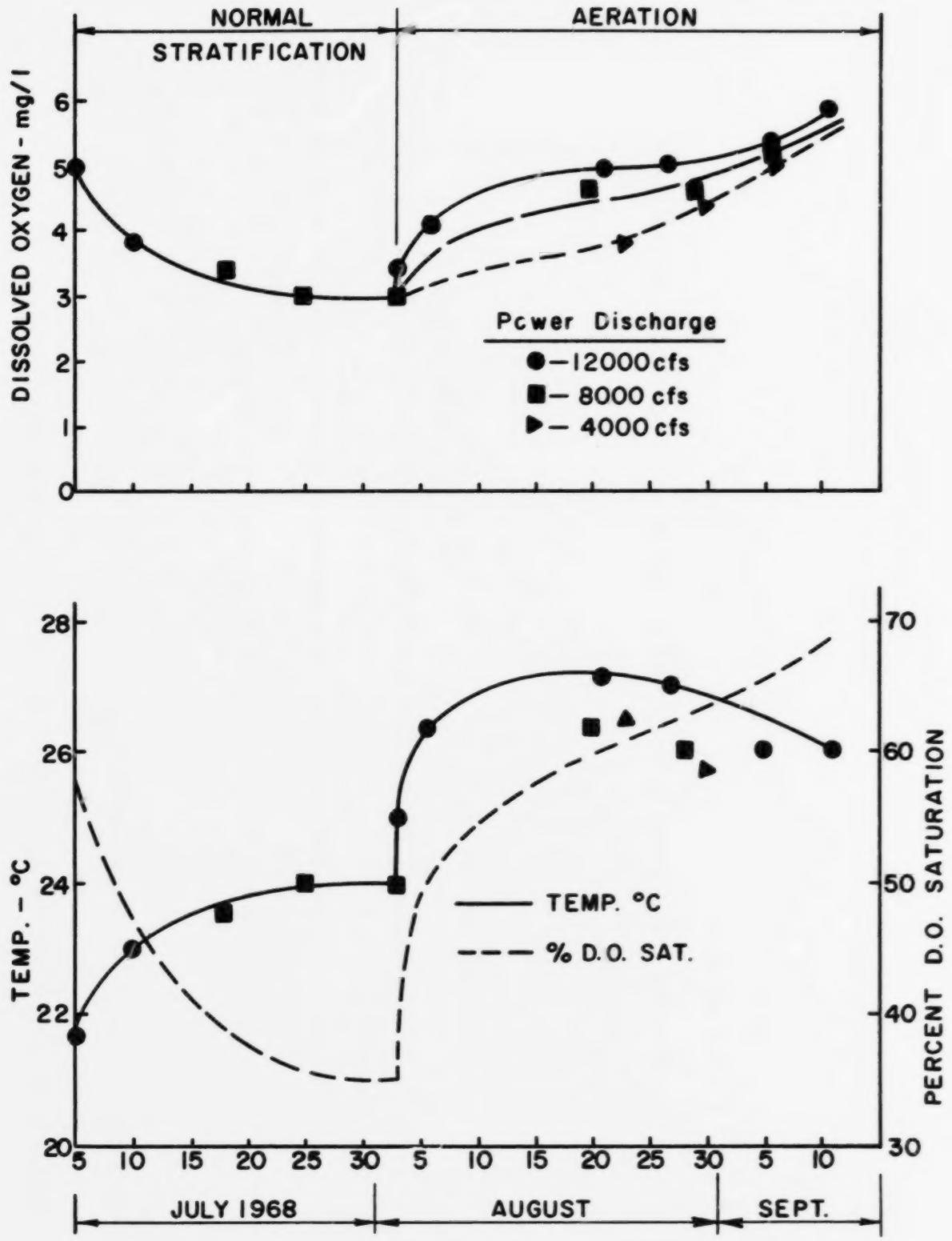


FIGURE 8 - EFFECT OF AERATION ON POWER RELEASE

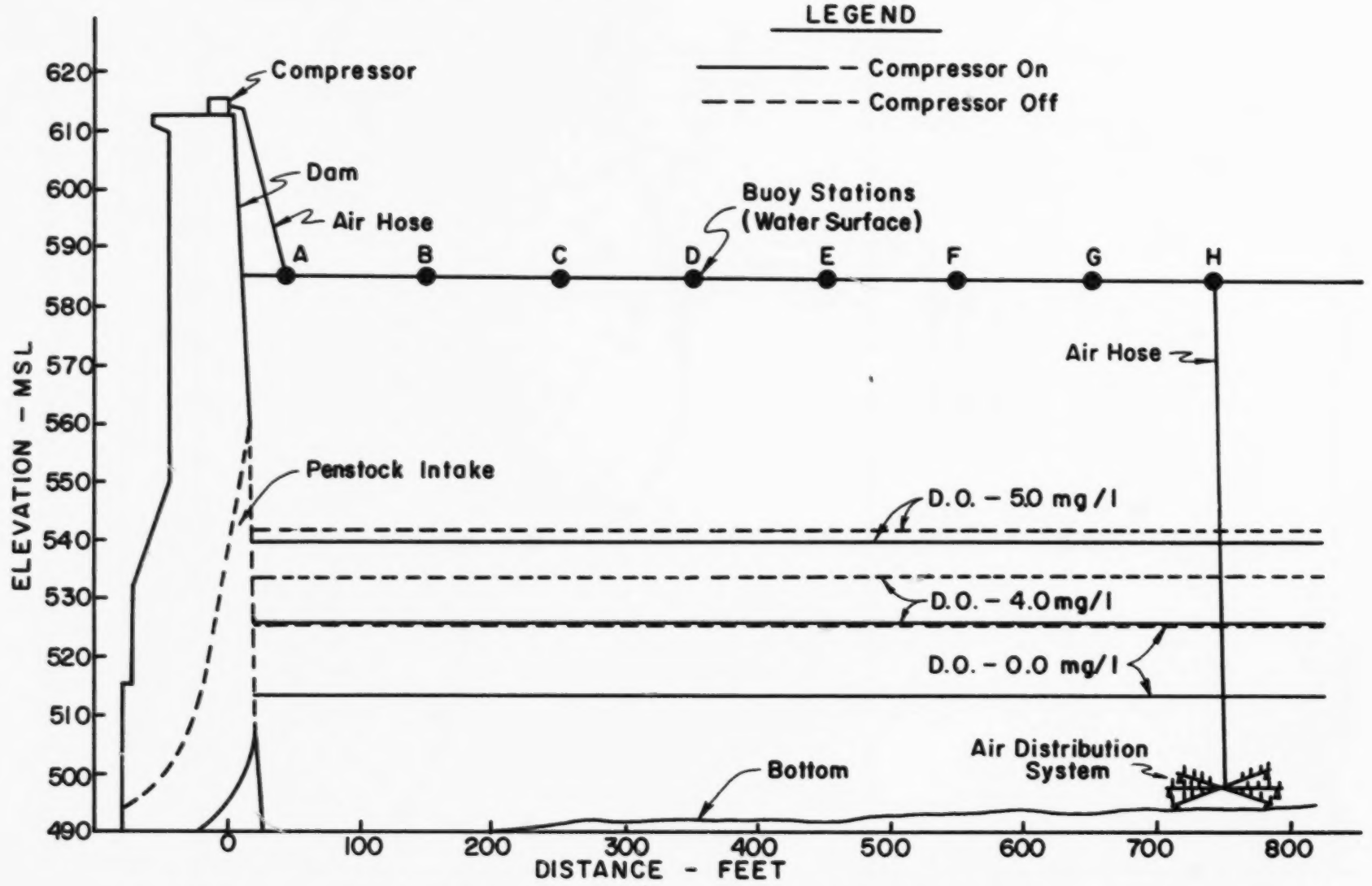


FIGURE 9 – EFFECT OF AERATION WITHOUT POWER RELEASE

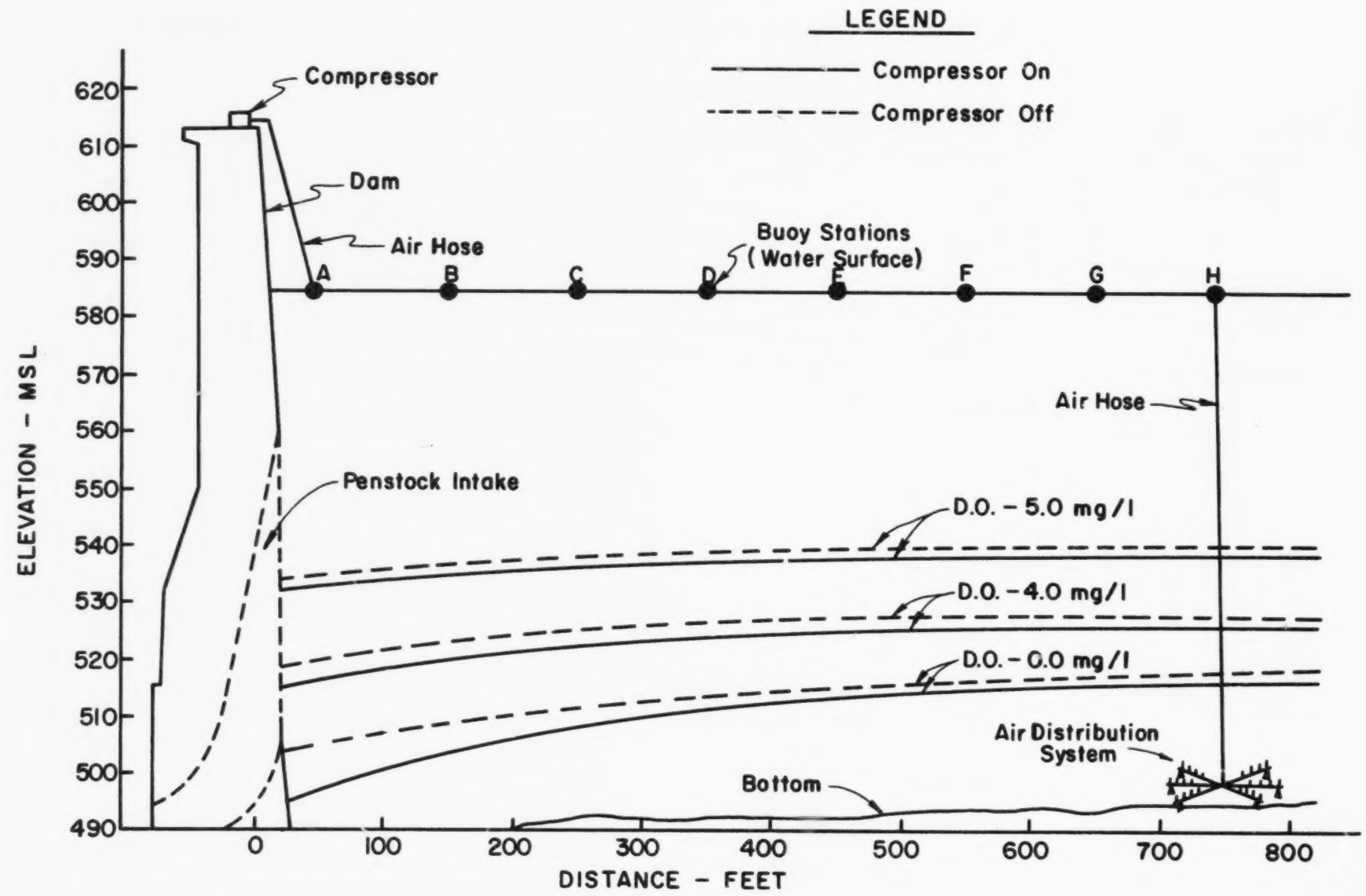


FIGURE 10 - EFFECT OF AERATION DURING 4000 cfs POWER RELEASE

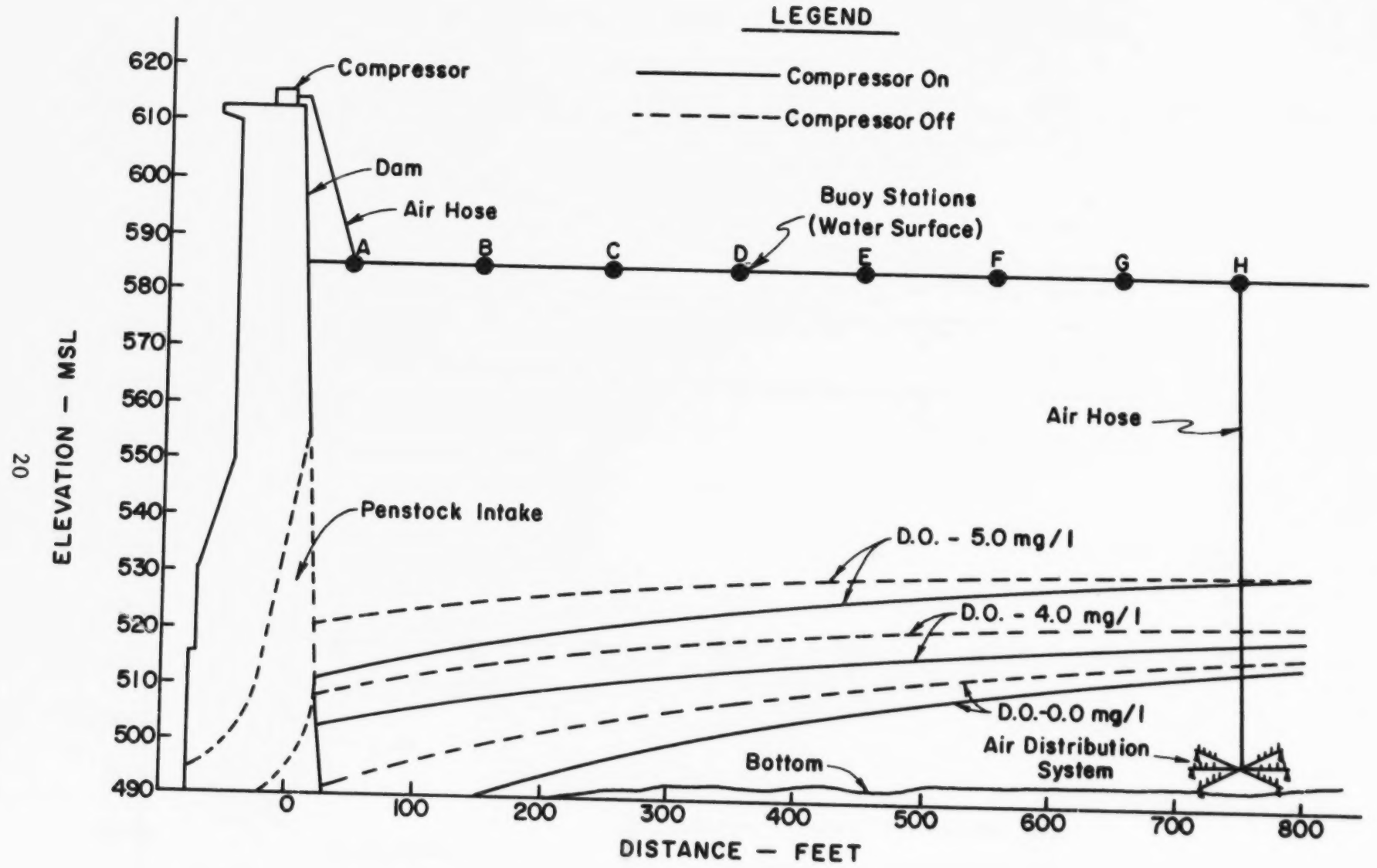


FIGURE II - EFFECT OF AERATION DURING 8000 cfs POWER RELEASE

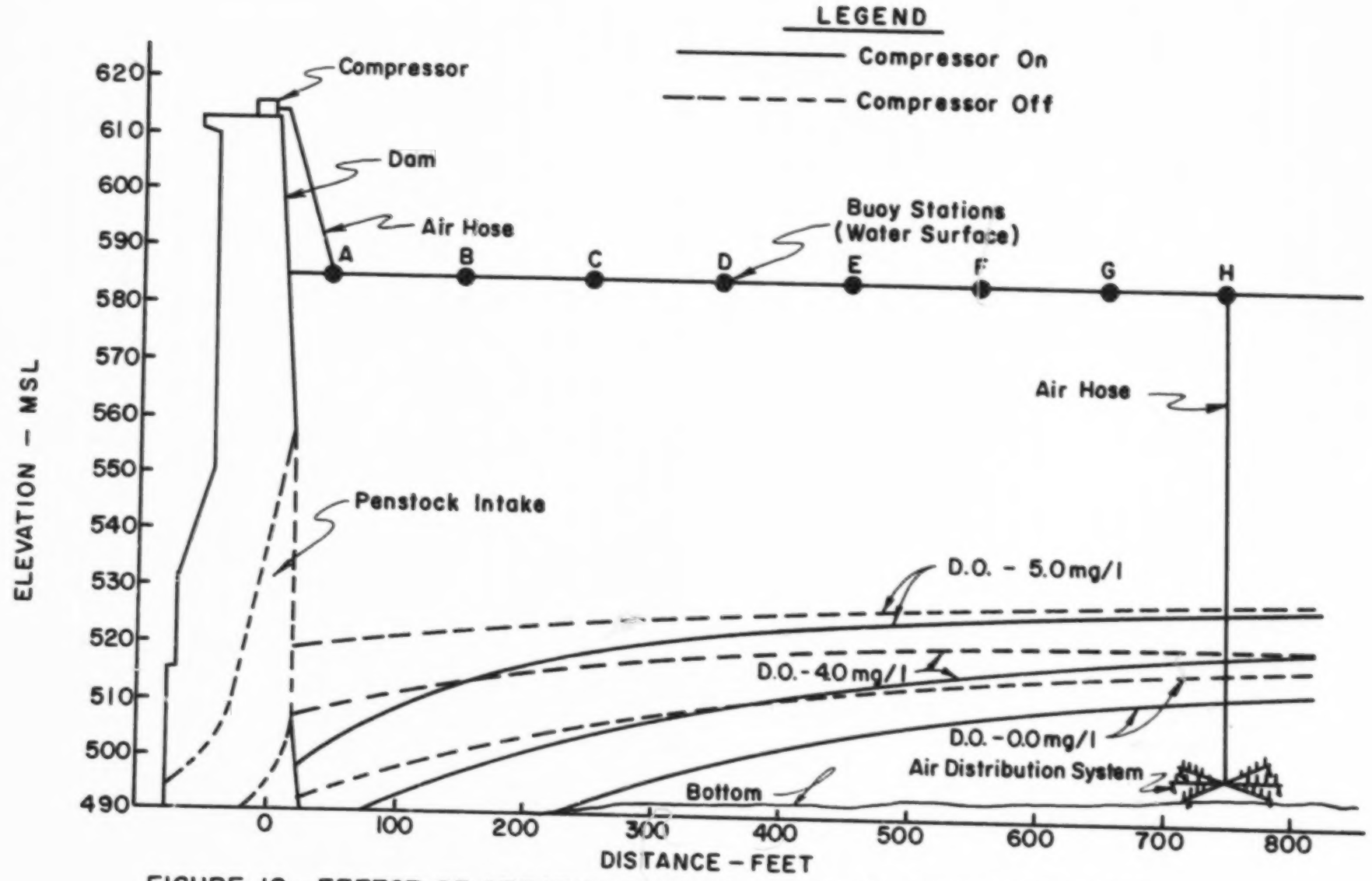


FIGURE 12 - EFFECT OF AERATION DURING 12000 cfs POWER RELEASE

Flow net conditions between the aeration unit and the turbine intakes were influenced by both the intake velocities of the three power discharge rates and the induced aeration operation (compare Figures 10, 11, and 12). Power releases under normal operating conditions suppressed the dissolved oxygen strata in the vicinity of penstock intake structures. The effect of continuous aeration at a constant rate was to further suppress the dissolved oxygen strata for the same flow conditions. It should be pointed out that conditions illustrated in Figures 10, 11, and 12 for periods in which there was no induced aeration are averages for one-week periods. Flow nets for each discharge rate were very stable, however, and exhibited only a slight variation from the average conditions.

Flow nets shown under conditions of induced aeration illustrate effects on the dissolved oxygen strata for three separate power discharge rates. They characterized the maximum condition during the total operating period. The dissolved oxygen concentration of 4.0 mg/l was suppressed completely to the reservoir bottom, immediately in front of the dam during aeration at peak power release (Figure 12). Data from the final days of aeration show that the oxygen levels of the flow net had reached near stable conditions. It is obvious from these profiles that the induced aeration unit increased the dissolved oxygen content of the hypolimnion upstream from the power intakes causing increases in the dissolved oxygen content of all power discharges. The actual volume of aerated water for each power release rate is represented by the area between the initial and changed dissolved oxygen levels upstream of the dam.

Following stratification, dissolved oxygen concentrations in the power discharges became stable for each discharge rate (2.9, 3.0, and 3.5 mg/l for 4,000, 8,000, and 12,000 cfs, respectively). These values were observed for a period of about a week prior to the strat of aeration on August 2 and were used as the base for analyzing the effect of power release aeration. A least squares regression analysis was performed using the expression $C = a+b\ t$ in which C = the concentration of dissolved oxygen in mg/l; t = time after the start of aeration in days; a = the intercept at time zero calculated from the standard least squares equation; and b = the regression coefficient or the slope of the least squares line. The least squares lines calculated from data collected during each release rate are shown in Figures 13, 14, and 15. At the beginning of aeration (intercept "a" at aeration time zero), the calculated dissolved oxygen concentrations were similar to the stable measured dissolved oxygen values for each of the discharge rates discussed above. The intercepts (a) are 2.88, 3.50, and 3.57 for 4,000, 8,000, and 12,000 cfs, respectively.

The regression analysis resulted in correlation coefficients of 0.961, 0.872, and 0.945 with standard errors of 0.192, 0.290, and 0.229 while the standard errors of regression coefficients were 0.029, 0.021, and 0.033 within 95% confidence for power discharge rates of 4,000, 8,000, and 12,000 cfs, respectively. With this information, it was possible to calculate a 95% confidence belt for any value of C for a given time t after the start of aeration for each of the three power discharge rates. The confidence belts are shown as curved lines about the least squares regression

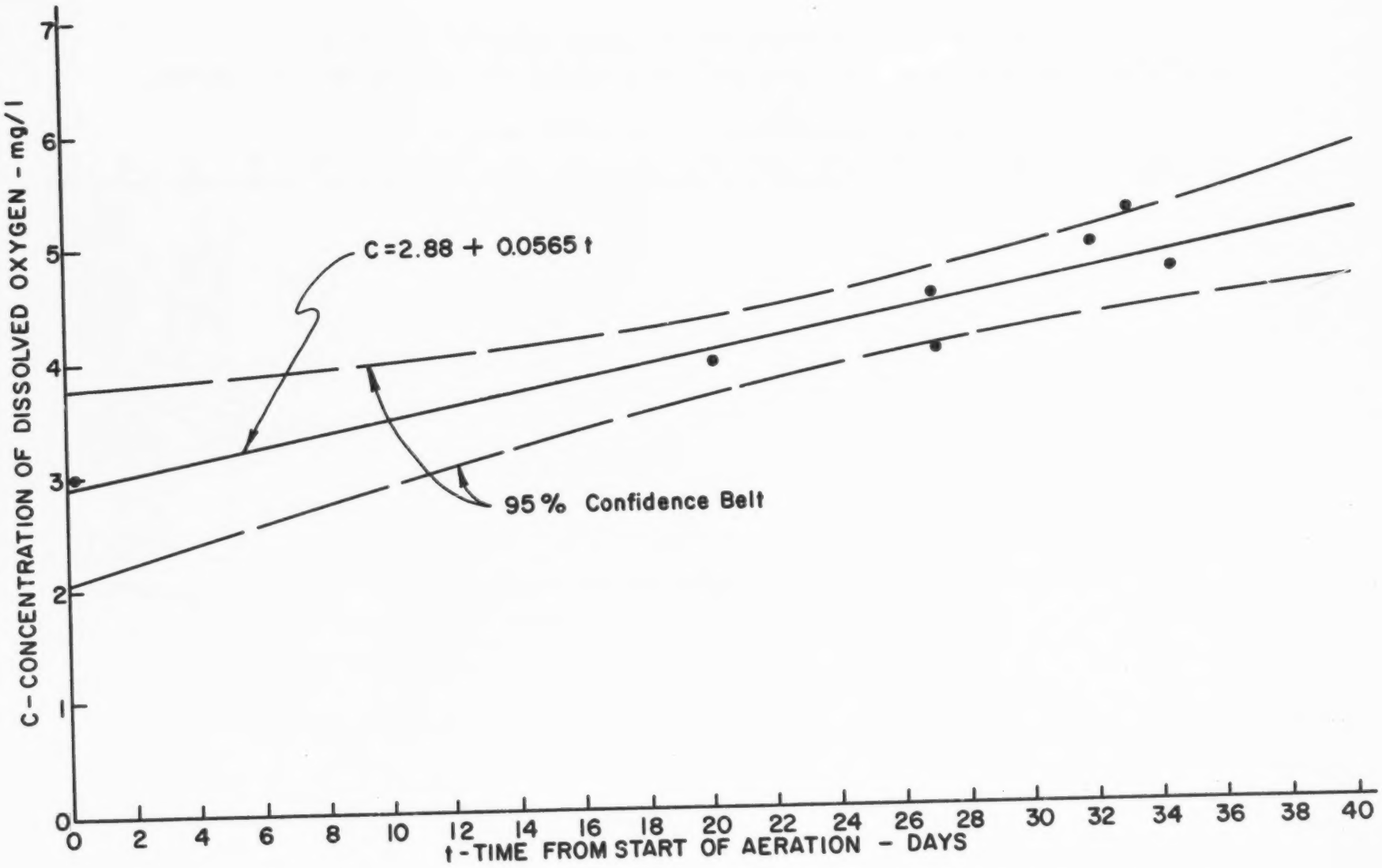
C=2.88 + 0.0565 t
95% Confidence Belt
C - CONCENTRATION OF DISSOLVED OXYGEN - mg/l
t - TIME FROM START OF AERATION - DAYS
0
1
2
3
4
5
6
7
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

FIGURE 13 - INCREASE OF DISSOLVED OXYGEN IN 4000 cfs POWER RELEASE PERIODS DURING RESERVOIR INDUCED AERATION

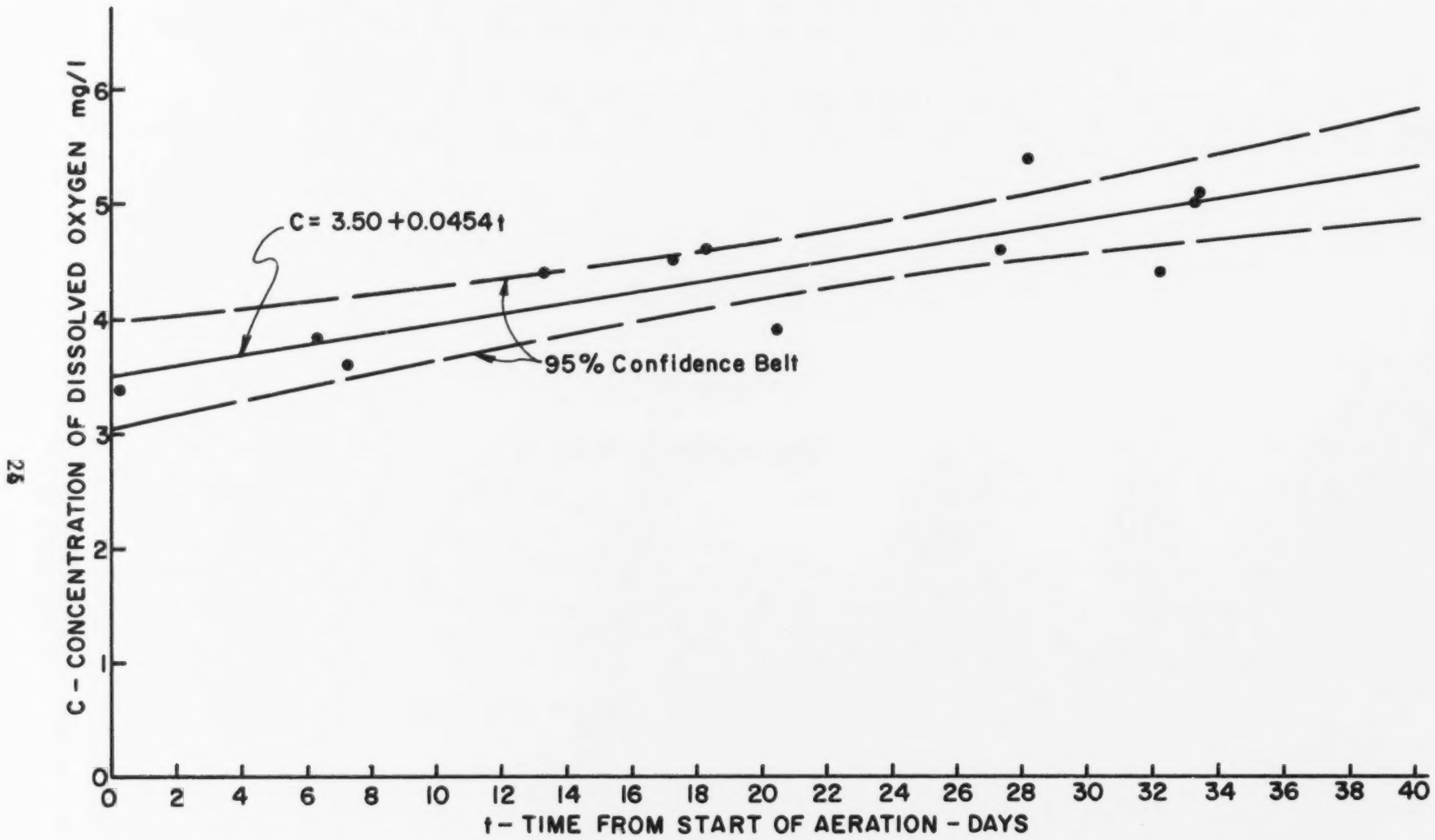
C = 3.50 + 0.0454 t
95% Confidence Belt
C - CONCENTRATION OF DISSOLVED OXYGEN mg/l
t - TIME FROM START OF AERATION - DAYS
0
1
2
3
4
5
6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

FIGURE 14 - INCREASE OF DISSOLVED OXYGEN IN 8000 cfs POWER RELEASE PERIODS DURING RESERVOIR INDUCED AERATION

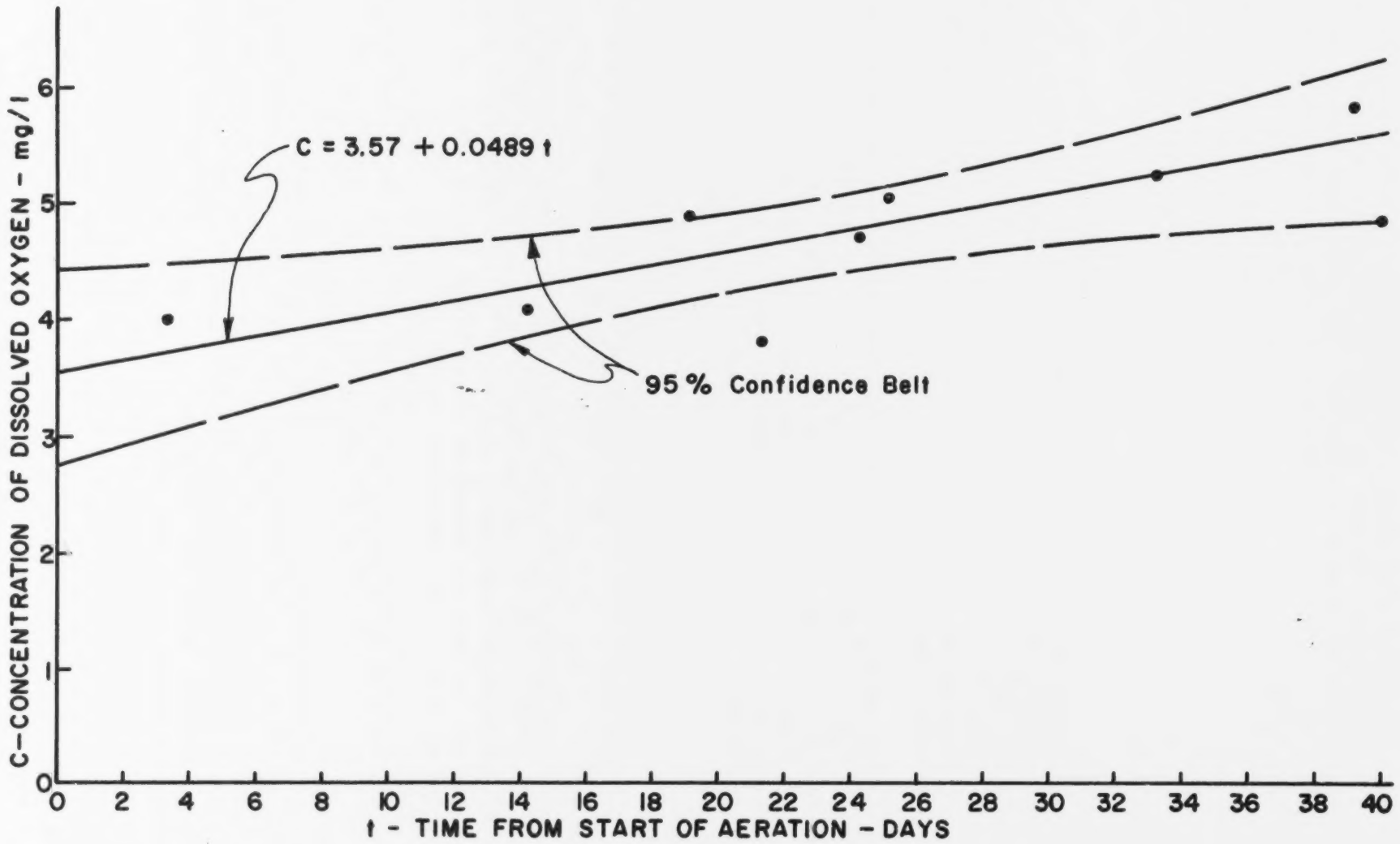
C = 3.57 + 0.0489 t
95 % Confidence Belt
C - CONCENTRATION OF DISSOLVED OXYGEN - mg/l
0
1
2
3
4
5
6
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
t - TIME FROM START OF AERATION - DAYS

FIGURE 15 - INCREASE OF DISSOLVED OXYGEN IN 12000 cfs POWER RELEASE PERIODS DURING RESERVOIR INDUCED AERATION

lines. From the regression analysis, it was possible to calculate the most probable rate of oxygen increase in each of the power release rates resulting from upstream hypolimnion aeration. The estimated oxygen increase resulting from the 40-day study for 4,000 cfs release periods was from 2.88 to 5.14 mg/l, for 8,000 cfs release from 3.50 to 5.32 mg/l, and for 12,000 cfs release from 3.57 to 5.53 mg/l. It should be realized that dissolved oxygen concentrations for each power generation rate would eventually become static. Static conditions would be reached when the water mass reaches saturation or the aeration system had reached its maximum aeration capacity for the flow release condition.

Temperature of the release water at the beginning of aeration was 24°C with a corresponding dissolved oxygen saturation of 35 percent (Figure 8). The temperature of the release rose from 24°C to a maximum of 27.2°C during the intensive study followed by cooling due to lower atmospheric temperatures. The oxygen saturation of the releases during peak temperatures reached about 61 percent. The saturation after that time was partially influenced by the lower atmospheric temperatures.

During the 40-day study period, the compressor was operated 750 hours, pumping a total of 49.73 million cubic feet of air equivalent to 931 thousand pounds of oxygen through the distribution system. By calculating the increased oxygen content from the three regression analysis and applying these increased oxygen concentrations to the volumes of power release at the specific time of release, it was found that 69 percent of the oxygen pumped into the reservoir passed through the dam. The fate of the remaining 31 percent of the oxygen pumped into the reservoir could not be determined. However, the data show that a portion was absorbed in the water mass upstream of the dam while the remainder was probably vented to the atmosphere.

As mentioned previously, only the dissolved oxygen values of power releases that were collected during the most stable power release periods were selected for detailed regression analysis. Total calculated dissolved oxygen added to the release was based on flow volume during each specific power generation period during the 40-day study and the oxygen increase at specific times of power generation. These calculations, when compared to the Kilowatt hours of power required for air delivery, resulted in an efficiency of 3.0 pounds of dissolved oxygen added to the power releases per horsepower-hour of energy expended. However, when results of regression analysis of all dissolved oxygen values measured in the power release--regardless of the stability of discharge--were used for comparison, efficiency was found to be 1.8 pounds of dissolved oxygen added per horsepower-hour of expended energy. Electrical installation and power costs for 750 hours of aeration was $2,625, resulting in an operation cost between $4.10 and $6.25 per thousand pounds of oxygen added to the releases.

Research conducted on releases at Eufaula Reservoir illustrates a feasible, economic way of managing the quality of power releases at dams where hydraulic features have not been designed for maximal quality purposes. The level of oxygen saturation in power releases was increased by the aeration unit at the three discharge rates studied. The oxygenation

efficiency of this system (1.8 to 3.0 pounds of oxygen transferred per horsepower-hour) compares favorably with other systems recently reported (Table 2). Values in Table 2 are referenced and include efficiency of oxygen transfer for aeration systems including turbine aeration. Efficiency range of the present study is considered conservative since increased dissolved oxygen concentrations in the reservoir for periods of no release were not used in the calculations. Further development of induced aeration systems may indicate they should be considered in design of outlet works of future dams. Additional research is necessary to develop this induced aeration system and optimize its design characteristics. Induced aeration research should take two separate avenues: first, the system should be developed to optimize the quality of releases, and second, it should be developed for water quality control in impoundments. In developing the aeration system to optimize the quality of release waters, a detailed study should be conducted in which selected chemical parameters--in addition to temperature and dissolved oxygen--are evaluated in the discharge, particularly nitrogen and hydrogen sulfide. Additional research is necessary to define optimum upstream placement and depth of air release for maximum dissolved oxygen retention in the flow net. The research should include additional testing of size and geometry of the distribution system with respect to volumes and pressures of compressed air. In conducting the study, every effort should be made to test the effects of aeration during several days of uninterrupted discharge for each of the normal power operating rates.

The development of aeration systems for water quality management of the entire impoundment by seasonal destratification should be accomplished through an economic evaluation based on a mathematical model. The model should be developed utilizing data from several recent studies. Development would include location of the optimum number and size of distribution systems based on the radiating effect of the air plume, depth and volume of air release, and pressure of induced air as well as physical shape and dimensions of the impoundment. After the model has been satisfactorily tested on available data, a reservoir should be selected and predicitions made with the model as to number, size, and spacing of distribution units required for specific aeration effects. The reservoir should then be field tested and the mathematical predictions verified.

TABLE 2

OXYGENATION CAPACITY FOR VARIOUS AERATION SYSTEMS

| Method | OXYGENATION EFFICIENCY | |
|---|---|---|
| | lb. $O_2$ transferred/Kw-Hr. | lb. $O_2$ transferred/Hp-Hr. |
| 1. Present Study | 2.4 - 4.0 | 1.8 - 3.0 |
| 2. Diffused Air Wahnback Reservoir (7) | 1.2 | 0.9 |
| 3. Hypolimnion Mixing Wahnbach Reservoir (7) | 2.1 | 1.6 |
| 4. Diffused air Baldency Lake (7) | 0.33 | 0.25 |
| 5. Lake Pfaffaker (7) | 4.3 | 3.2 |
| 6. Turbine Aeration (7) | 1.3 - 5.6 (range)<br>2.4 average | 1.0 - 4.2 (range)<br>1.8 |
| 7. Turbine Aeration (7) | 4.3 - 5.6 ($O_2$ Saturation below 10 percent) | 3.2 - 4.2 |
| 8. Activated Sludge (7) | 3.1 (Coarse bubble) | 2.3 |
| 9. Aero-Hydraulic Gun (8,18) | 1.4 | 1.0 |
| 10. Boltz Lake Mechanical Pump (4,19) | 1.0 | 0.75 |
| 11. U-Tube Stream Aerators (20) | 3.3 | 2.5 |
| 12. Stream Spray Aerators (21) | 1.1 - 2.1 | 0.8 - 1.6 |
| 13. Vented Power Turbines (21) | 2.4 - 2.8 | 1.8 - 2.1 |
| 14. Mechanical Stream Aerators (21) | 2.1 - 2.5 | 1.6 - 1.9 |
| 15. Stream Surface Aerators (21) | 1.1 - 2.3 | 0.8 - 1.7 |
| 16. Diffusor Stream Aerators (21) | 0.8 - 1.9 | 0.6 - 1.4 |

## SECTION V

## ACKNOWLEDGMENTS

The authors express their sincere appreciation to the U. S. Army Corps of Engineers, Tulsa District, Tulsa, Oklahoma, especially the Operations and Engineering Divisions, without whose cooperation access to an adequate power supply and suitable compressor site would not have been possible. The authors are also grateful to the Southwestern Power Administration, Tulsa, Oklahoma, for cooperation in making provisions for a high voltage electrical power source on Eufaula Dam.

This research study was conducted in cooperation with the Oklahoma Cooperative Fishery Unit, Bureau of Sport Fisheries and Wildlife, Oklahoma State University, Stillwater, Oklahoma, under direction of Dr. Robert C. Summerfelt. The Oklahoma Cooperative Fishery Unit conducted extensive fish distribution and productivity studies in connection with destratification effects in the central pool of Eufaula Reservoir.

A study to establish the vertical distribution of fish in Eufaula Reservoir was conducted under the direction of Mr. Robert M. Jenkins, Director, National Reservoir Research Program of the Bureau of Sport Fisheries and Wildlife, U. S. Department of the Interior. Its contribution to this research is greatly appreciated.

## SECTION VI

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Environmental Protection Agency
Robert S. Kerr Water Research Center
Ada, Oklahoma

6 Title

INDUCED HYPOLIMNION AERATION FOR WATER QUALITY IMPROVEMENT OF POWER RELEASES,


10 Author(s)

Leach, Lowell E.
Duffer, William R.
Harlin, Curtis C., Jr.


16 Project Designation

16080---10/70

21 Note

22 Citation

23 Descriptors (Starred First)

*Aeration, *Thermal stratification, *Impoundments, *Hypolimnion, Dissolved oxygen, Mixing, Oxygenation, Air entrainment, Thermocline, Epilimnion

25 Identifiers (Starred First)

*Water quality control, *Induced aeration, *Reservoir destratification, *Hypolimnion aeration, Air distribution system, Oxygenation efficiency, Power release aeration


27 Abstract

Conventional hydraulic structures in most dams withdraw low flow and power releases from the poor quality hypolimnion waters during summer stratification resulting in serious degradation of long reaches of streams below dams. Induced aeration of hypolimnion waters during summer stratification has great potential in water quality management of power releases, low flow releases, and limited volumes of impoundments without costly modification of existing outlet works. Hypolimnion aeration research on power discharge quality improvement was conducted at Eufaula Reservoir in southeastern Oklahoma during the summer of 1968. Dissolved oxygen transfer efficiency of the aeration system ranged from 1.8 to 3.0 pounds of dissolved oxygen per horsepower-hour of expended energy resulting in an operating cost of 4.10 to 6.25 dollars per 1,000 pounds of oxygen incorporated into the power releases. Additional research for development and optimization of the induced aeration system is discussed.



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WR:102 (REV. JULY 1969)
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